Development and Testing of a Datalogging Device for Physiological Measurements of Deep-Diving Odontocetes

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Award Number: N00014-11-1-0537
http://www.alaskasealife.org

LONG-TERM GOALS

There is a dire need to determine the normal cardiovascular dive response of deep-diving odontocetes like beaked whales, and to examine how that response might be altered during exposure to anthropogenic sound. However, no one has ever recorded the electrocardiogram of a wild, free-ranging odontocete. Recent advances in the miniaturization of multi-channel datalogging devices now make it possible to conceive of remotely attaching a device to a deep-diving odontocete to record physiological variables such as heart rate and body temperature, which would then permit studies of the cardiovascular response to diving and advance many of the discussions about the susceptibility of beaked whales to gas bubble disease beyond theory and speculation.We will modify our existing technology for making physiological recordings and demonstrate its utility on beaked and pilot whales so that diving physiology studies could be conducted to further our understanding of the susceptibility of these whales to adverse physiological effects of exposure to anthropogenic sounds.

OBJECTIVES

1. Improve on our existing technology for making physiological recordings so that future studies can be conducted to understand susceptibility to adverse effects of exposure to anthropogenic sounds

    1.1. Modify our solid-state electrocardiogram (ECG) and dive behavior monitor for use on pilot and beaked whales and other deep diving odontocetes

    1.2. Deploy on pilot and/or beaked whales to prove feasibility and collect preliminary data on the physiological response to diving

APPROACH

We plan to make the necessary changes to our current physiological recording device and to conduct test deployments of the device on either pilot or beaked whales. The ECG amplification and filtering circuit we used on our initial pilot whale tests did not produce clear cardiac signals with the close

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Development and Testing of a Datalogging Device for Physiological Measurements of Deep-Diving Odontocetes**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Alaska Fairbanks and the Alaska Sealife Center P.O. Box 1329 Seward, AK 99664**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**5**	

electrode spacing that is achievable with a single "T-pole" deployment system. Therefore, we will modify the ECG circuit to increase gain while still attempting to filter out the EMG noise that is likely to be picked up from the muscles in the vicinity of the attachment sites.

We have demonstrated that it is possible to attach an ECG tag using a 2-pole system, but we need additional practice to perfect this technique. We anticipate that with additional field time, we will then be able to successfully attach our modified ECG tag, getting both of the suction cup/electrode darts to firmly attach with sufficient separation, resulting in the recording of a clear ECG.

Encounter rates with short-finned pilot whales off Hawai'i are normally quite high. Short-finned pilot whales are similar in body size to beaked whales, making them a good test surrogate morphologically, and being deep divers they will expose tags to a similar environment of cold, high pressure ocean water. This deep diving behavior of pilot whales means that they also deserve scientific attention to their diving physiology and susceptibility to gas bubble disease. Therefore, we will propose to conduct our test deployments off the island of Hawai'i where we can conduct test deployments on at least two species of beaked whales and short-finned pilot whales.

WORK COMPLETED

This project provided us with funds to procure three new multi-channel behavioral and physiological recording devices, and to spend three days on the water in Hawaii to attempt deployments of the tags in order to record the electrocardiogram (ECG) of either pilot or beaked whales. We have built three different ECG amplification and filtering circuits to test variations of gain and band-pass filter limits. We have also built one set-up that incorporates a pre-amplifier directly on each electrode that incorporates a very high input impedance and a low output impedance, which we hoped would improve the biopotential signal, which can be degraded due to poor contact between electrode and skin and the movement of the electrode cables. Each archival tag included flotation for when the tag falls off the whale, and sitting on top of each float we have incorporated the usual VHF beacon as well as a very small SPOT5 location-only satellite transmitter. The addition of the satellite tag beacon should drastically improve our odds of finding the tag after it falls off the whale. We conducted tests with our various circuits and determined that the best ECG amplication and filtering circuit combinations were an amplication of either 2500X or 5000X, and a bandpass of 10 – 50 Hz. We worked with Wildlife Computers to obtain a customized Mk10 tag with extra external channels and wired our ECG circuitry to three new tags – two with the 2500X amplifier and one with the 5000X amplifier. The main body of the tag is pictured in Figure 1, where you can see the recording device, flotation, suction-cups containing the primary ECG electrode, VHF beacon, and SPOT5 satellite tag. Figure 2 shows the complete unit with a coiled cable running to the secondary electrode.

We conducted field work off the Kona coast of the island of Hawai'i from October 18 to November 13, 2011. The primary purpose of that field work (funded by ONR and NOPP) was to conduct follow-up studies of previously tagged odontocetes, but we added extra field days to accomodate the ECG tag testing, and were prepared to deploy the ECG tags on days when short-finned pilot whales were encountered and could be approached close enough to attempt the ECG tagging. On 30 October 2011, we successfully attached one of the ECG tags to a pilot whale. The tag stayed attached for appoximately 8 hours and after it fell off the whale, we easily retrieved it with the aid of the satellite tag and VHF beacons. In this deployment, the suction cup that was originally closest to the head of the whale did not contain a dart, and the suction cup that contained the primary ECG electrode dart was positioned more towards the tail. This allowed the tag body to rotate around the anchoring point of the

back end of the tag as the whale swam through the water, and this caused substantial motion artifact on the ECG channel. The spinning of the ECG dart and barbs also probably resulted in poor contact with the tissue. Additionally, a bug in the tag's internal program revealed itself during this deployment, and the ECG and accelerometer channels included large artifacts. Therefore, no useful ECG signals were observed in the record from this deployment. Engineers at Wildlife Computers attempted to troubleshoot the problem, but that was not possible while we were in the field. Instead we modified an older datalogging tag that didn't include accelerometers but that had different tagware lacking the bug. With this tag we positioned the primary electrode with the dart at the front of the tag to better stabilize it and prepared for another deployment attempt. Unfortunately we were not able to get another opportunity at a good ECG tag deployment on the rest of that Oct/Nov 2011 trip.

We had another opportunity to attempt ECG tag deployments during a research cruise off the Kona coast of the island of Hawai'i from 05 to 24 May 2012. That trip was funded by other sources, primarily our ONR-NOPP tagging improvements and follow-up study, as well as an ONR-funded study to apply D-Tags to melon-headed and false killer whales. We again prepared one of the older tags that didn't have the tagware issues, and were able to make two deployment attempts on that trip. On the first attempt, the tag hit the flank of the whale at a bit of a steep angle, and the titanium dart snapped upon impact, and the tag did not attach. It appeared that the dart penetrated less than 1cm, and the whale was sighted a couple of days later with no signs of the dart remaining. These electrode darts were built with a single row of very small barbs that were only 5 mm long, so we believe the broken dart was not achored well and fell out quickly. We then rebuilt the electrodes on this and another tag so that the titanium electrode darts were much more resistant to this kind of failure. We had one more opportunity to deploy an ECG tag on a pilot whale during this trip, but on that attempt the electrode suction cup/dart assembly did not fully seat and although the tag stayed attached for 12 hours and was successfully recovered the next day, no discernible ECG was recorded.

We then worked with Wildlife Computers to procure completely new multi-channel data logging tags that properly recorded without unusual noise at 128 Hz on all channels, including built-in sensors for depth, external and internal (tag) temperature, three accelerometer channels, and three external channels. Three of these tags were modified to include our ECG biopotential amplifier and prepared with ECG electrodes, flotation and satellite tag and VHF beacons. We then joined another research cruise funded by ONR for D-tagging off the Kona coast of the island of Hawai'i from 16 – 25 August 2012. Although we had very few opportunities where pilot whales could be easily approached for ECG tagging, we did make three attachment attempts. In each case, we were not able to successfully apply both the main body of the tag and the tethered secondary electrode.

RESULTS

We have yet to successfully record the ECG of a freely-diving whale, but we have learned a tremendous amount about the challenges involved in this endeavour and have devised many solutions that should bring us very close to being able to achieve our goal. Unanticipated problems with the dataloggers slowed us down, but now that we have a good datalogging system we do not expect any additional troubles on that front. Our biopotential amplifier circuit appears very capable, and so our major challenge is how to apply the complete tag assembly to a moving whale from a moving boat. We initially built an ECG tagging system that included two electrodes that were closely spaced and that could be deployed with a single pole by a single person. Unfortunately the voltage difference between the two electrodes so closely spaced on these whales was too small to result in recognizable heart depolarization waveforms in the ECG. That is why we switched to a two pole, two person system that

allows us to achieve reasonable separation between the two electrodes. However, with this system it is fairly important that both parts of the tag make contact with the whale simultaneously because even a small reaction by the whale can make it impossible to properly attach the second piece of the tag. Additionally, the curvature of the body of a pilot whale makes it difficult to get a fairly perpendicular attachment when using a long, inflexible pole. Therefore, we are now working to completely modify the suction cup/electrode dart assemblies to allow them to attach properly even when they initially touch down at a acute angle relative to the body of the whale. We have requested a no-cost-extension for this project and plan to use the small amount of remaining funds we have to make improvements to the method of tag deployment so that we are more likely to be successful when attempting to place the ECG datalogging device onto the moving whale. We will then try to join an on-going field project in the first half of 2013 in order to attempt once more to successfully record the ECG of a freely diving whale. We hope to be successful in attaching our tag and recording the ECG during deep diving in pilot whales, and then we can make recommendations on how this task could be accomplished in the future with critical species, such as beaked whales, that are even more difficult to approach and tag.

IMPACT/APPLICATIONS

Understanding the potential for impacts of naval activities on protected species of marine mammals and mitigating such impacts requires information on basic physiological and behavioral parameters that are currently a mystery. Demonstration of the successful operation of these physiological recording devices on free-ranging cetaceans will be a breakthrough and should lead to follow-up research on the cardiovascular dive and exercise responses of deep-diving odontocetes. Follow-on studies could include deployments on a sufficient sample size of beaked whales in order to gather the data necessary to adequately understand the physiological mechanisms involved in the potential for gas bubble disease as a consequence of behavioral disturbance in beaked whales.

RELATED PROJECTS

The National Oceanographic Partnership Program and ONR are supporting our project “Improving attachments of remotely-deployed dorsal fin-mounted tags: tissue structure, hydrodynamics, in situ performance, and tagged-animal follow-up.” That project provided the primary funding for field work in October-November 2011 and May 2012 in Hawai’i. The goals of that project are to improve upon our satellite tagging methodology to achieve longer, less variable attachment durations by carefully examining the factors that affect attachment success, along with follow-up studies of whales that have been tagged with a remotely-deployed dorsal fin-mounted tag to accurately quantify wound healing and the effects of tagging on whale survival, reproduction, and behavior. The National Marine Fisheries Service Pacific Islands Fisheries Science Center is supporting research on false killer whale movements in Hawaiian waters, and the Naval Postgraduate School (with funding from N45) is supporting tagging studies of a variety of species in Hawai’i. See: www.cascadiaresearch.org/hawaii/beakedwhales.htm and www.cascadiaresearch.org/hawaii/falsekillerwhale.htm .

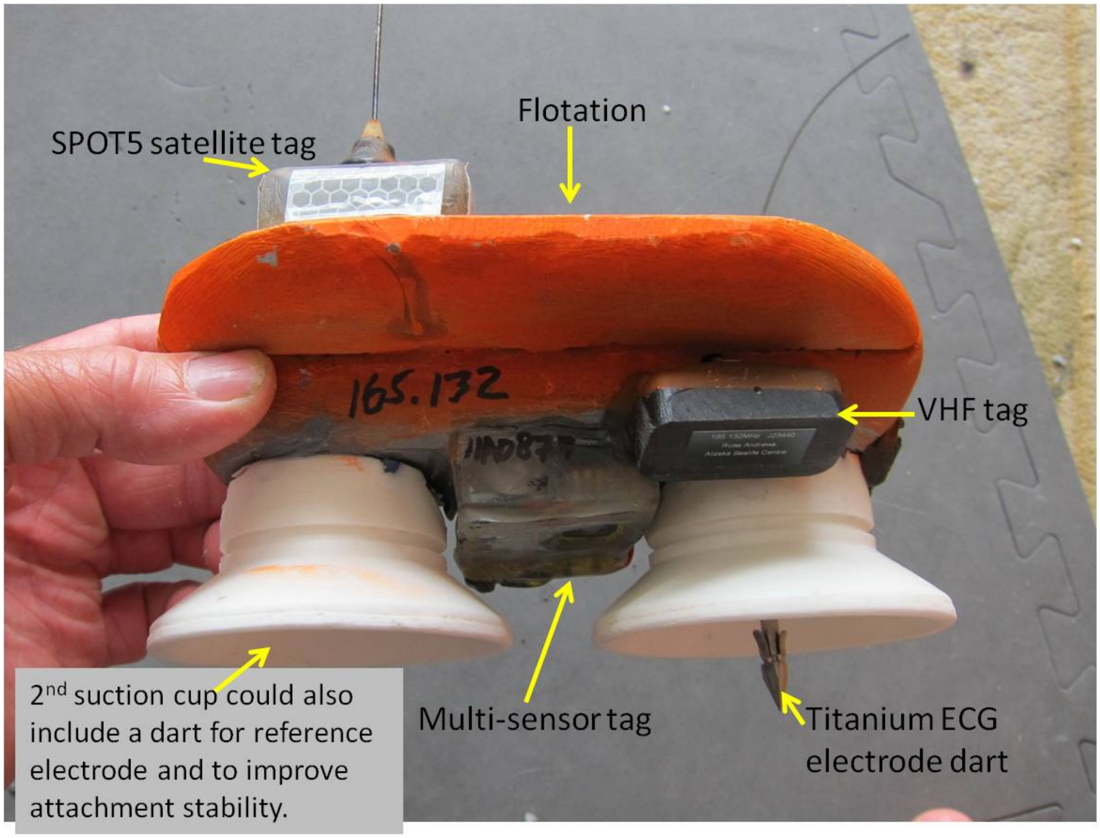

Fig. 1. Main body of multi-sensor tag for recording dive behavior and the electrocardiogram (ECG) of whales.

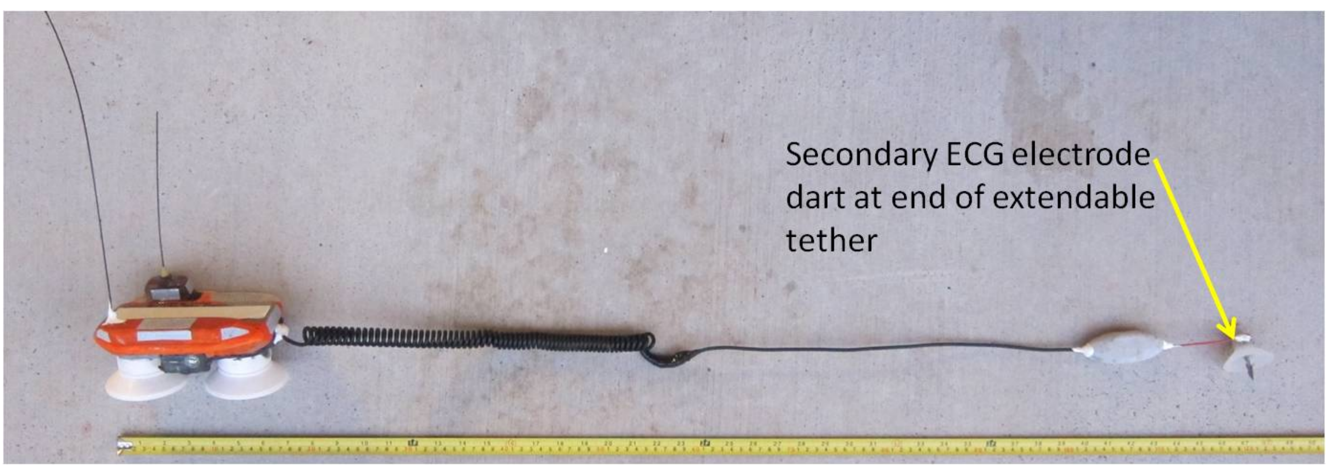

Fig. 2. Main body of multi-sensor tag on left with coiled cable running to the secondary electrode on right.